ELECTRICAL WIND ASSIST WATER PUMPING[1]

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ABSTRACT

Most modern wind turbines are designed to generate utility compatible AC electric power. The easiest way to use these wind turbines for irrigation pumping is by intertieing with the electric utility grid. However, because irrigation pumping requires large amounts of power during critical crop growth stages and minimum power during the non-growing season, utilities have to supply power during peak load times and purchase power during off peak times.

Five wind turbines having induction generators have been operated in water pumping experiments at Bushland, Texas. These turbines ranged in rated capacity from 25 to 100 kW and have included both horizontal- and vertical-axis types. All units have operated at least 5,000 hours, with one unit having been operated for over 20,000 hours. Performance curves, monthly energy production, percentage of run-time, and availability are given for each turbine.

INTRODUCTION

Wind power has traditionally been used to pump water. Asians used wind power to lift water into rice paddies, while Europeans have used windmills to pump water into the sea so that land can be reclaimed for agricultural production. Another major use of wind power has been to supply a year-round water supply for livestock and domestic needs. In the semiarid plains of North America, a year-round water supply allowed permanent habitation of the fertile grasslands. These traditional windmills produced less than 1 kW and were the sole source of power for the pumping system. The volume of water delivered using the piston pump normally ranged from 0.2 to 0.5 ℓ/s.

Irrigation pumping requires large amounts of power because crops like corn, rice, cotton, and wheat transpire 1.2 cm of water per day, thus requiring a flow of 1.0 ℓ/s per hectare. This is the amount of water that must be available all through the growing season. Irrigators prefer to have between 30 and 50 ℓ/s available from their pumps. Power requirements then range between 10 and 150 kW, depending on the lift and discharge pressure. In 1980, farms in the United States used an estimated 90 billion kilowatt-hours of energy for irrigation pumping. Electricity, natural gas, and diesel fuel were the major forms of energy used. Irrigation pumping energy accounts for 40 to 70% of the energy used on farms where irrigation is practiced. Sixty-three percent of the energy used in irrigation pumping is used in the plains regions of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, and Texas where an abundant supply of wind energy exists.

Irrigation creates a seasonal load for electric power companies because most pumping occurs in June, July, and August. This heavy load corresponds with the summer air conditioning load, creating severe summer peak demands. Therefore, electric power companies reluctantly add new installations and often charge high demand rates. Farmers are seeking new and alternate energy sources for pumping irrigation water.

Electrical wind-assist pumping systems consist of a wind turbine producing utility compatible electricity that is intertied to the utility at the load center (Fig. 1). A wind turbine operating in a wind-assist mode will, first of all, supply power to the load nearest the wind turbine-utility connection, then any excess will be supplied to other loads before passing through the meters and transformer to be fed into the utility system. Thus, the wind

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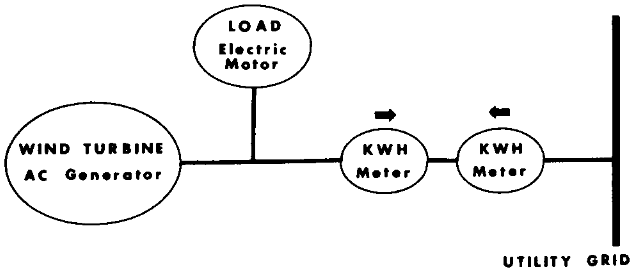

FIG. 1 SCHEMATIC OF ELECTRICAL CONNECTION FOR A WIND-ASSISTED PUMP USING AN INDUCTION GENERATOR

turbine generator becomes an interactive system with the utility grid, and power flows forwards and backwards through the service entrance and meter.

The wind-assist pumping concept has several advantages over a wind-alone concept: 1) water can be pumped and distributed to the crops during critical water-use periods regardless of windspeed, 2) a constant pump speed is maintained for good pump efficiency and optimum well yields, 3) the system is easily adapted to existing irrigation pump installations without exchanging pumps or other existing equipment, and 4) a consistent water flow permits efficient application of irrigation water and good water management. A shortcoming of the electrical wind-assist concept is that it requires a connection to the electric utility with associated demand charges.

Most wind machines built for commercial sales in the United States are of the induction-generator type. These units require that the generator be directly connected with the electric utility for excitation of the generator. Many large induction generators are three-phase, 480-volt systems, similar to electric irrigation service. Three wind turbine units with induction generators have been examined for irrigation pumping at the USDA Conservation and Production Research Laboratory, Bushland, Texas, and two other units were used to pump water for the city of Canyon, Texas.

Wind turbines were purchased for individual projects through competitive bids and were used in different pumping situations.

Carter 25[3]

The Carter 25 is a 25-kW, horizontal-axis wind turbine with two blades and a rotor diameter of 10 m. This system is unusual in that both the spar and the blades are fiberglass. The unit unloads in high winds due to the flexibility of the spar. Other specifications of this unit are given in Table 1. The unit at Bushland was installed in August 1979 and operated until January 1982 as a three-phase, 240-volt system. This unit was the first sold by Carter Wind Systems and received several design modifications during its first year of operation. During the 29 months of operation, the unit produced 69,977 kWh and was available (the switch was in automatic) 65% of the time. A power curve for the system was determined and is shown in Fig. 2. The turbine begins producing power at a windspeed of approximately 4 m/s and reaches its peak power of 26 kW at 14 m/s. In windspeeds above 14 m/s, the fiberglass blades flex, thus shedding excess power and not overloading the generator.

While this unit was being moved in 1982, it was changed to a three-phase, 480-volt system and all the latest design features were incorporated. Most design changes were in the electronics and control system while the tower, gearbox, rotor, and generator were all retained. Table 2 contains monthly performance data from June 1982 through November 1983 for this unit. During this 18-month period, the generator was energized, producing power 8,251 hours or 63% of the time and produced 52,060 kWh. The unit was available (the switch was in automatic) 88% of the time. Downtime included routine maintenance, damage to control system caused by lightning, and excess wear in the teetering hub assembly (1, 2). This unit averaged almost 460 hours operation per month and produced nearly 3,000 kWh per month, where the average windspeed, at a 10-m height, was 5.9 m/s.

Two other Carter 25's were installed at the water well field of the city of Canyon near Bushland. Data were collected from these units from March 1981 through June 1983. One unit produced 60,910 kWh and was available 76% of the time, while the other one produced 71,070 kWh with an availability of 74%. These units experienced more downtime because they were 22 km from town and were normally checked two or three times per week instead of daily as was the unit at Bushland.

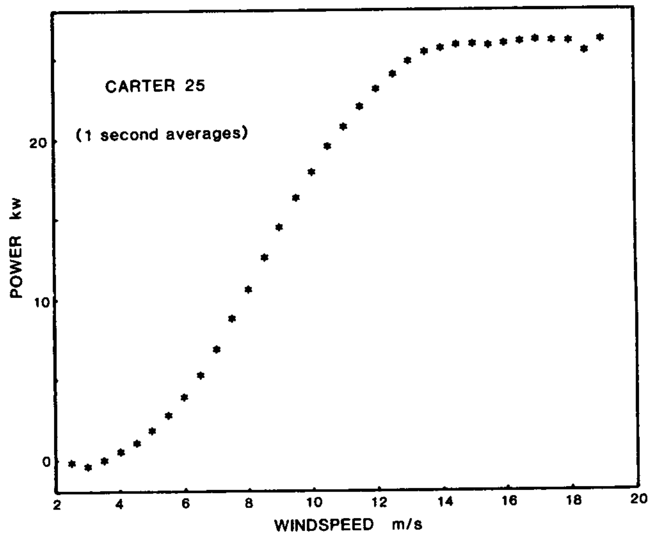

FIG. 2 POWER CURVE FOR THE CARTER 25, CORRECTED TO STANDARD AIR DENSITY

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3 Trade names and manufacturer's model numbers are given for informational purposes only. Wind units used in USDA testing were purchased by USDA through competitive bids. No endorsement is given or implied to any manufacturer.

Enertech 44[3]

This horizontal-axis wind turbine features a 13.4-m diameter, three-bladed, fixed-pitch rotor mounted on a 24.4 m free-standing tower. The blades are fabricated from laminated epoxy-wood, and are attached to a steel hub. Table 1 contains the specifications of this wind energy conversion system.

The Enertech 44 produces utility-compatible electrical power by employing a 240 V, single-phase induction generator. Capacitors of 160 mFd are installed with the 25-kW generator to improve the power factor and generator efficiency. Slip-rings are used to transmit the power from the generator to the load.

Installation of the Enertech Model 44 at Bushland, Texas, was completed on May 26, 1982. The machine was operated on a "shakedown" basis until June 14, 1982, at which time the unit was placed in full-time operation.

The machine was initially operated with the blade pitch offset two degrees from design to reduce the loading on the gearbox, generator, and brakes. After a new brake was installed, it was determined that a higher power output could be reached without overloading the system. On March 1, 1983, the blade pitch was changed to one degree from design.

Power curves, shown in Fig. 3, were established for the wind turbine when the blade pitch was offset two degrees and one degree from design. Data, sampled at 4.5 times per second with a 15-second average, were utilized to produce the power curves. The data are corrected to an air density of 1.226 kg/m³ which represents standard density (sea level at 0° C). The cut-in windspeed was the same for both pitch settings. The maximum power observed was 23.2 kW, with a pitch of two degrees from design and 29.3 kW with a pitch of one degree from design. The reactive power varied from 2.9 kVARs at cut-in to 13.2 kVARS at the rated real power of 25 kW (3).

TABLE 1. Specifications of electrical wind turbines installed at Bushland, Texas.

	Carter 25	Enertech 44	DOE-100
Manufacturer	Carter Wind Systems	Enertech Corporation	Alcoa
Type	horizontal downwind	horizontal downwind	vertical Darrieus
Serial No.	1	2	2
Rotor			
No. of blades	2	3	2
Diameter, m	10	13.4	16.8 x 25.3
Swept area, m²	78	141	270
Rotational speed, rpm	120	53	48.1
Blade material	fiberglass	wood/epoxy laminate	extruded aluminum
Airfoil, NACA	23015		0015
Transmission			
Type	double reduction, helical	triple reduction, helical	parallel shaft
Ratio	15:1	34.5:1	37:1
Generator			
Type	three-phase, induction	single-phase, induction	three-phase, induction
Rated power, kW	25	25	100
Output voltage, VAC	480	240	480
Tower			
Type	guyed pipe	free-standing truss	platform
Height m	17	24.4	2.7
Performance			
Rated power, kW	25	25	95
Rated windspeed, m/s	11.6	13.4	13
Start-up windspeed	4.5	4.9	5.5
Cut-out windspeed	25	22.3	20.1
Rotor Speed Control			
Normal operating speed	aerodynamic stall	aerodynamic stall	aerodynamic stall
High windspeed shutdown	blade pitch change	control applies brake	control applies brake
Emergency rotor overspeed	blade pitch change	tip brake deploy	emergency brake

TABLE 2. Summary of performance data for Carter 25 and Enertech 44 wind turbines, Bushland, Texas.

Month	Carter 25				Enertech 44				Windspeed @ 10 m
	Operating time		Energy produced	Avail-ability	Operating time		Energy produced	Avail-ability	
	hrs	%	kWh	%	hrs	%	kWh	%	m/s
June 1982	405	50	3,148	76	---	--	---	---	5.3
July	123	16	253	39	474	68	4,947	100	5.6
Aug	423	59	1,481	98	478	60	2,984	100	4.6
Sept	503	72	2,468	99	525	73	4,536	100	5.5
Oct	418	67	2,300	100	516	69	5,023	98	5.5
Nov	373	44	2,970	65	441	61	5,292	98	6.3
Dec	255	36	2,343	48	410	59	5,135	99	6.8
Jan 1983	451	59	2,574	100	286	37	2,806	81	5.2
Feb	474	67	3,606	100	344	49	3,642	76	5.8
Mar	526	70	4,224	100	512	69	5,989	98	6.2
Apr	521	69	4,280	95	476	64	5,922	100	6.7
May	527	73	3,883	100	537	68	6,769	100	6.6
June	563	78	3,710	100	539	75	5,959	100	6.2
July	588	79	3,483	99	584	79	6,290	100	6.2
Aug	463	60	890	81	301	41	1,836	82	4.4
Sept	543	80	3,480	99	474	68	5,823	81	6.4
Oct	583	78	3,387	100	543	71	6,753	100	5.8
Nov	513	69	3,580	86	469	65	5,979	92	6.3
TOTAL	8,251		52,060		7,909		85,685		
AVG	458	63	2,892	88	465	64	5,040	94	5.9

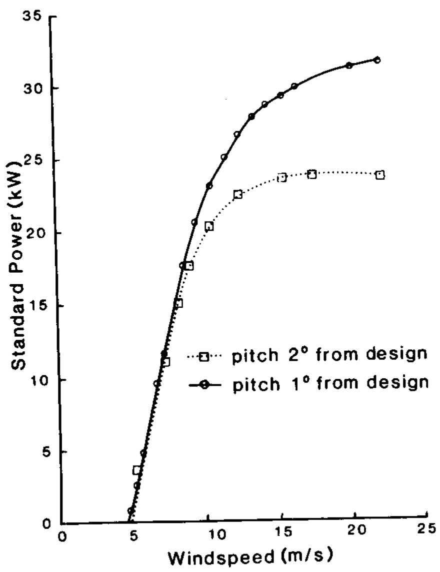

FIG. 3 POWER CURVES FOR THE ENERTECH 44, CORRECTED TO STANDARD AIR DENSITY WITH ORIGINAL TIP BRAKES

The Enertech 44 has been available to operate 94% of the time between June 1982 and November 1983 (Table 2). During this period, the generator was energized 7,909 hours and produced 85,685 kWh. The Enertech 44 was energized 465 hours per month, almost the same as the Carter 25; but because of its larger diameter, produced more energy.

The Enertech 44 has operated well during the 18-month period at Bushland. In addition to some design changes (new brakes, tip brakes, etc.), only three repairs were needed. Two of the repairs involved replacement of the rotor rpm sensor and the other one was replacement of the brake control relay. All repair, maintenance, design changes, and inspections resulted in less than 6% downtime (3).

DOE 100 kW[3]

A 100-kW vertical-axis wind turbine was built for the Department of Energy, Sandia Laboratories, Albuquerque, New Mexico, by Alcoa Laboratories in 1980. Unit No. 2 was installed at the USDA Conservation and Production Research Laboratory, Bushland, Texas, in March 1981. The turbine is 29 m high and the top is supported by three steel guy cables, each 4 cm in diameter. The two blades are extruded aluminum with a 61 cm chord and four internal ribs for bracing. Table 1 contains several of the important specifications for this unit. The wind turbine has a three-phase, 480 volt induction generator and provides electricity to an irrigation pump and center-pivot sprinkler system, as well as supply power for an environmentally controlled data collection building.

The power curve for the 100-kW wind turbine is similar to most vertical-axis units but does not exhibit the reduced power at high windspeeds (Fig. 4). The power produced by the rotor was measured by a torque sensor before entering the transmission. The electrical output shown in Fig. 3 represents the usable power supplied at the main disconnect of the wind turbine system. The power losses in the transmission and induction generator averaged about 12% over the range from 0 to 100 kW and were uniform at about 10% when power was above 50 kW. A peak rotor efficiency of 48% has been measured at a tip-speed ratio of 5 (4).

The turbine has operated 5,882 hours and produced 163,224 kWh during 32 months of operation. The turbine has been used primarily as a research machine for collecting stress-strain data rather than energy production data. Also, the turbine has had two major design changes that required almost 6 months of downtime. The guy cables were increased in size to increase the stiffness of the top and a lowspeed brake was installed to replace the original highspeed brake.

LOAD ANALYSIS

Wind turbines produced power year-round, whenever sufficient wind is available. Monthly electrical energy production for the Enertech 44 is shown in Fig. 5 along with a typical monthly energy use from an 18.7 kW electric irrigation pump. The wind turbine normally produces between 5,000 and 6,000 kWh per month, except in August. January and February would be in that range, but were low because of icing on wind turbine blades

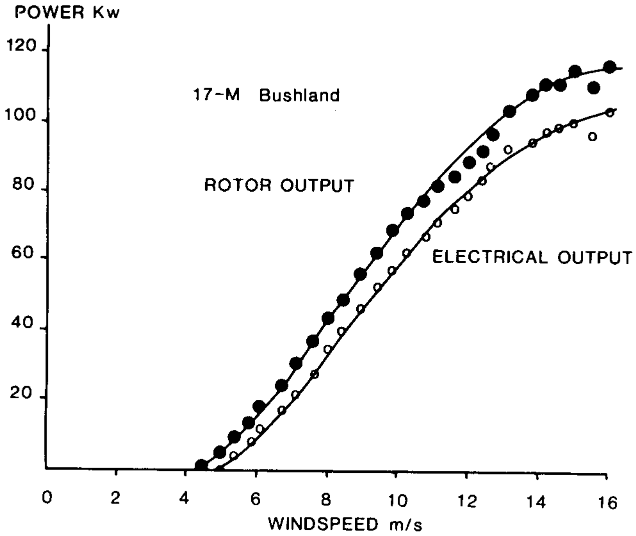

FIG. 4 ELECTRICAL POWER AND ROTOR POWER FOR THE 100 kW, VERTICAL-AXIS WIND TURBINE, CORRECTED TO STANDARD AIR DENSITY

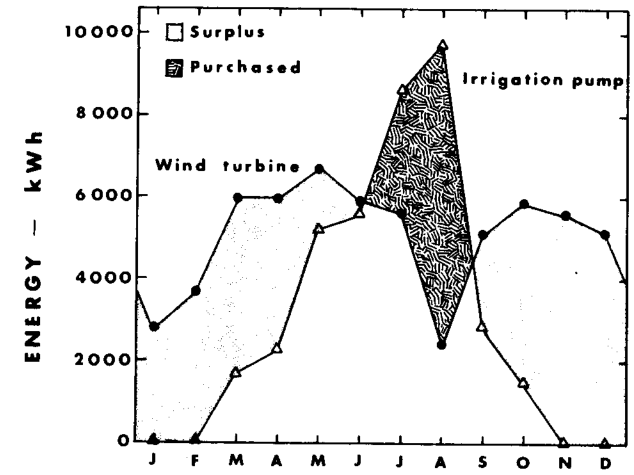

FIG. 5 MONTHLY ENERGY PRODUCTION FROM THE ENERTECH 44 AND SIMULATED MONTHLY IRRIGATION ENERGY USE. SHADED AREAS REPRESENT SURPLUS ENERGY SOLD AND DEFICIENT ENERGY PURCHASED. WHITE AREA UNDER CURVE IS ELECTRICAL ENERGY DISPLACED BY THE WIND TURBINE.

in 1983. From Fig. 5, the wind turbine should produce sufficient power to meet the irrigation load in all months except July and August. With this simulated load, the wind turbine would produce 60,952 kWh of which 27,102 kWh would be used by the irrigation pump and an additional 10,298 kWh would be required to meet the pump demand in July and August.

The DOE 100-kW and a Carter 25 are connected through a common load center with two irrigation pumps, a center-pivot sprinkler system, and an environmentally control data collection trailer. Energy production and use data for this load center are shown in Fig. 6. The first bar for

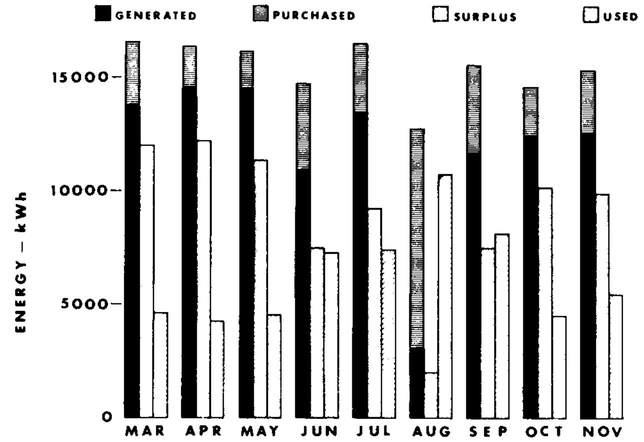

FIG. 6 MONTHLY ENERGY GENERATED BY THE CARTER 25 AND 100 kW, ENERGY PURCHASED FROM THE UTILITY, SURPLUS ENERGY SOLD TO UTILITY, AND ENERGY USED BY THE DATA TRAILER AND IRRIGATION PUMP

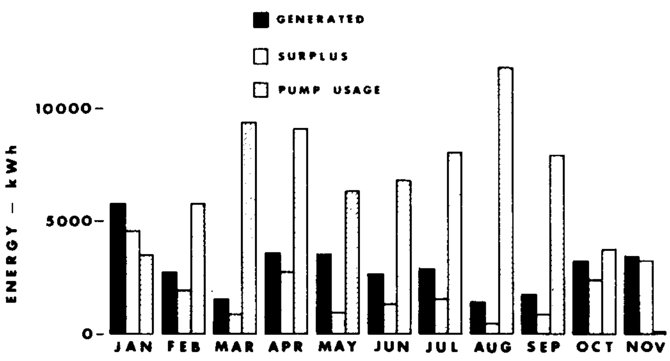

FIG. 7 MONTHLY ENERGY GENERATED BY A CARTER 25, SURPLUS ENERGY SOLD TO UTILITY AND ENERGY USED BY A 37 kW PUMP WHILE PUMPING WATER FOR THE CITY OF CANYON

each month is a combination of wind generated electricity and purchased electricity. Even though significantly more electricity was produced than used, some electricity was purchased each month. Also, a significant percentage of wind generated electricity was fed into the utility system regardless of the amount used on site.

A third example of wind powered water pumping is shown in Fig. 7. These data are for a Carter 25 at the water well field, city of Canyon, where the load was a 37-kW deep well pump. In this case, the pumps ran all year and were cycled on/off in relation to other pumps and city water requirements. Again, a significant portion of the wind generated electricity was fed back into the utility grid rather than being used by the pump even though the pump was much larger than the wind generator. No attempt was made to control pumping time to match available wind power in either case presented in Figs. 6 or 7.

Wind power can provide significant amounts of power for irrigation pumping, but some type of load management or control is needed to minimize the feedback of wind generated electricity and to minimize the pumping time when no wind power is available.

SUMMARY

Wind powered irrigation systems must be capable of supplying the needed amount of water at the critical plant water stress periods, which occur in mid-summer for most crops. During this time period, wind power alone would have difficulty in supplying all of the needed power. However, with the electrical wind-assist systems, the extra energy can be purchased from the utility. With proper management, the wind system could supply most of the energy requirements except for the months of July and August.

In any wind electric system that is intertied with the utility, the load should be less than the peak output of the wind turbine. If the load is equal to or greater than the peak wind turbine output, the contribution will be minimal. Also, the contribution will be minimal with a seasonal load rather than a year-round load.

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